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About the MATLAB Measurement and Control Technology of Thermal Power Machinery

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Abstract: Computer technology is developing in the direction of low cost, low power and small size, hardware production process and structure volume are no longer the main factors limiting the development of measurement and control(MaC) system, now the reason that hinders the rapid development of the system is the design of software development tools. Software development tools can significantly reduce the MaC system software design work on the programmer's requirements, does not require systematic learning to develop the complete architecture of the system, hardware language and other professional knowledge, only need to receive little learning and training can be completed for the purpose of system development. Among these software development tools, MATLAB software has become the representative of such tools with its powerful functions and simple operation. Therefore, in this paper, we have developed a MaC system for an internal combustion engine(ICE), a thermal power machine, and optimized the performance of the MaC system on the MATLAB simulation platform(SP).

1. Introduction

The rapid development of the ICE electronic control technology is inseparable from the development and use of basic MaC technology, MaC technology continues to innovate to make the ICE electronic control possible, the use of advanced MaC technology to the development process has brought great convenience, has become an essential means of ICE electronic control technology research and development process. Modern ICE electronic control technology to a high degree of intelligence, refinement direction, is bound to be a variety of comprehensive use of MaC technology, which is also increasing the requirements for supporting MaC technology.

There are many studies on thermal power mechanical MaC, focusing on the testing of steam engines, ICEs, gas turbines and other mechanical devices. For example, the ICE MaC test bench is an important research condition in the study of electronic control technology for ICEs. A powerful,

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high-performance, easy-to-use, stable and reliable test bench has a multiplier effect on the study of electronic control technology. With the help of the test bench, on the one hand, the control method and control strategy can be tested to see if the control effect is as expected, and on the other hand, the control method and control strategy can be continuously improved and optimized according to the test results [1-2]. The electronic control of ICE is a multifaceted and complex system, and its multifaceted complexity is reflected in the diversity of control objects and the coordinated and orderly actions among different control objects to ensure the normal operation of the ICE. The optimal control of ICE fuel injection, exhaust valves, etc. by means of electronic control ensures that the ICE works under any operating conditions with the best performance index to achieve the requirements of safety, energy saving and environmental protection [3]. Some domestic and foreign research institutions and ICE manufacturers have built test platforms to improve their control strategies and product performance in the process of research on ICE electronics [4]. Some foreign companies have built test rigs for RT-Flex type intelligent ICE electronically controlled exhaust valve drive characteristics analysis and reliability testing, with the help of which drive control units and control strategies are developed and continuously improved and optimized [5]. However, regardless of the development of MaC technology, the ultimate goal of its development is always to improve the comprehensive performance of thermal power machinery.

This paper firstly introduces MATLAB software and establishes the SP jointly with Simulink; then takes the ICE MaC system as an example, establishes the ICE nozzle model and data acquisition model, and realizes the data acquisition work of the signal to be measured in the MaC system FPGA; finally analyzes the performance of the MaC system on the SP, compares the simulation results with the experimental results, and verifies the effectiveness of the MATLAB SP to calculate the performance coefficient.

2. MATLAB Software and SP

2.1. Software Introduction

MATLAB software applies the M language and implements programs in the form of mathematical calculation symbols as well as formulas. Since it has the advantage of simplicity and efficiency compared to other development software, it has quickly become one of the most popular software in the field of scientific and engineering calculations as well as computer control [6]. After the development and expansion of this software in various professional fields, it has become more powerful graphical programming capabilities, which makes the application of MATLAB even more widespread.

Simulink is an important component module of MATLAB software, which is used as a graphical interactive tool for dynamic simulation and modeling. The tool has a well-optimized human-machine interface and is compiled in a modular way to compile complex and intuitive computational methods and control programs. The ease of modification and portability of the program enhances the user convenience [7-8]. The application of Simulink to build control models is easy to learn, has a clear structure, high control accuracy and compilation efficiency, and fits closely with actual experiments, so it is widely used in signal control, analysis, and processing [[9].

2.2. MATLAB/Simulink SP

The program block diagram established by Simulink can then be used as the human-computer interface for this program, and the entire program can be compiled by mouse action only. The

process of writing the program is easy as long as the modeling idea is correct and well-organized, and there is no need to consider the compatibility and correctness of the complicated program code.

Click the Start Run icon on the Simulink model building window to simulate and calculate the model. In addition, you can also enter the corresponding commands through the MATLAB command window to complete the simulation and calculation process. By adding an oscilloscope module to the model, the target data can be monitored in real time, and the correctness of the model can be verified by comparing the change pattern of the data with the actual situation.

3. ICE MaC System

3.1. MaC System to be Measured Signal Analysis and Sensor Selection

The MaC system mainly collects the actual signals inputted by the fuel injection system, cylinder oiling system and exhaust valve system in the form of sensors and the instructions and parameters received/issued in the form of communication. The sensor measurement signals correspond to the main technical indicators of the three electronic control systems, which can be divided into two categories: (1) monitoring of the state parameters of the three electronic control systems, such as servo oil pressure and temperature in the servo oil stabilizer block, servo oil flow in the fuel injection control chamber, displacement of the boost piston and other signals; (2) control signals characterizing the control performance of the electronic control unit, such as boost control signals, solenoid valve drive current [10-11].

The signals to be measured by the MaC system include the main performance parameters of the electronically controlled fuel injection system, electronically controlled cylinder oiling system, electronically controlled exhaust valve system and auxiliary system, with many types of signals and high signal quality requirements [12]. As the source of each signal to be measured in the MaC system, it is crucial to select the appropriate test sensors for different types of measurement signals. In addition to the performance parameters of the sensor itself, such as range, accuracy, sensitivity and anti-interference, the sensor selection also needs to take into account the installation method, output type and reliability requirements to achieve the best balance of economy and performance [13].

3.2. Nozzle Modeling

The ICE mixture preparation method is carburetor type, but this method does not meet today's needs in terms of emissions as well as economy, so its injection method is modified to intake tract injection in the ICE bench test [14]. As shown in Table 1, the InjAFSensorconn nozzle model, which defines the air-fuel ratio of the mixture, was used at the time of the injector modeling.

Table 1. Air-fuel ratio of ICEs under different operating conditions

Rotational Speed(r/min)	Air-fuel ratio
1500	12.36
2000	15.41
2500	17.85
3000	18.24
3500	18.97
4000	19.23

3.3. Multi-Task Control Algorithm under Matlab

Since Matlab is generally used for computational analysis, it does not have its own multi-threaded programming method, which brings greater difficulties in writing real-time programs and multi-task linkage control. Although the traditional single-task control method can complete simple automation tasks, it is often time-consuming in relatively complex environments and lacks reasonable invocation of equipment, resulting in a waste of equipment and time, which is not in line with the real industrial process control environment, and does not meet the development trend of modern industrial MaC equipment [15-16]. Therefore, the implementation of real-time multitasking scheduling control of hardware in Matlab environment has become an urgent problem to be solved.

The ICE MaC system uses the throttle actuator as the inner loop and the engine speed as the outer loop to form a control loop. In the experimental process, it is impossible to establish an accurate mathematical model to characterize these control quantities because of the fast change rate and large change range of the control quantities. Therefore, the digital PID controller was selected and the execution of the control strategy was implemented by a computer, so that the flexibility and accuracy of this MaC system was improved [17].

$$\int_0^t e(n)dt \approx T\sum_{i=0}^{n} e(i) \tag{1}$$

$$\frac{de(t)}{dt} \approx \frac{e(n)-e(n-1)}{T} \tag{2}$$

T is the sampling period and n is the sampling sequence number. e(t) is the deviation signal and de(t) is calculated from the e(t) bias.

3.4. Data Acquisition Module

The data acquisition of this MaC system is divided into two ways: data acquisition by data acquisition card and serial port transmission. The RPM signal is acquired by the data acquisition card, and the engine torque, fuel consumption rate and emission parameters are transmitted by the serial port.

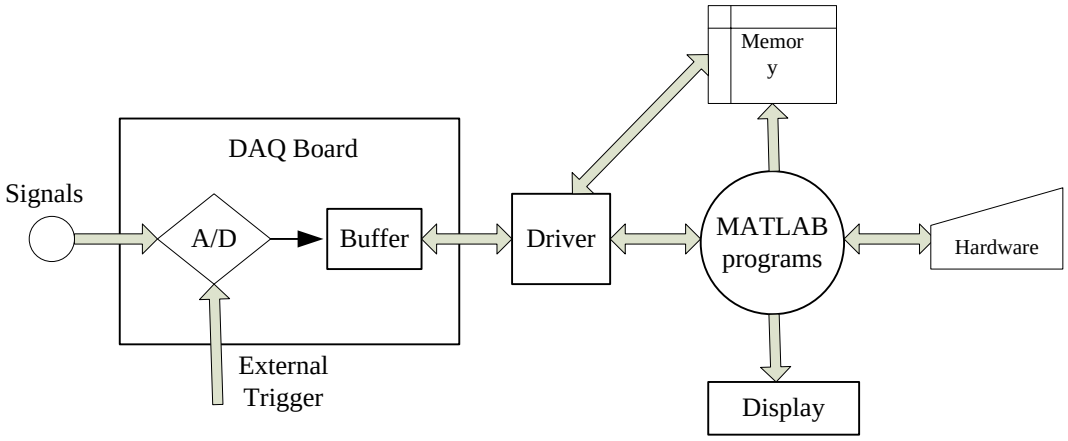


Figure 1. Data acquisition structure

Data acquisition is the most core and basic function of MATLAB software, and also the biggest advantage of the software, because it has a complete set of data acquisition program writing tools, these tools can fully meet most of the user's requirements, using it to develop a powerful data acquisition program. Analog signal data acquisition is one of the most common acquisition methods in data acquisition, and it is also one of the main application objects of MATLAB software, for which the software provides users with an easy-to-operate and functional analog signal acquisition system [18]. As shown in Figure 1, this figure represents the data acquisition structure of the data acquisition card. Before each data acquisition, the data acquisition card needs to be set up once for initialization to ensure the accuracy of the data.

3.5. High-Speed Signal Acquisition

The acquisition of all signals to be measured in the test bench MaC system is implemented in the FPGA.

Unlike the traditional DAQ program design where the acquisition process and acquisition parameters need to be configured one by one, the high-speed acquisition of signals is easier to program in FPGAs. The FPGA interface development mode is used to directly access the FPGA I/O nodes of each input module and configure the cycle execution time (i.e., sampling interval, also known as sampling period) to facilitate the next processing analysis.

FPGA data types do not support floating-point, most operations are done with plastic or fixed-point, especially fixed-point is widely used in FPGA. Fixed-point numbers, in simple terms, are different from floating-point numbers with variable precision and range, whose integer and fractional parts are constant in length. In practice, the acquisition of analog quantities is unified with the fixed-point number of each signal I/O module, while the fixed-point type of each signal I/O module is determined by its own resolution and the range of values it can recognize.

The ICE is a rotating machine with strict timing, its fuel injection, gas exchange and other processes are executed in accordance with the established phase, and the crankshaft angle is often used as the reference system for the study and analysis of various performances. All the signals to be measured, in addition to the conventional signal to characterize the performance, there is also a crankshaft angle analog signal. In order to realize the binding of all other signals with the analog signal of crankshaft angle and facilitate the performance analysis, the analog signal of crankshaft angle generated by the output signal of the photoelectric encoder after processing is collected simultaneously as one way signal [19].

4. MaC System Application and Optimization

4.1. Validation of the SP

In order to verify the accuracy and operational stability of the SP, the platform was used to perform the simulation calculation of ICE performance coefficients several times, and the average value of the calculation results was compared and analyzed with the composite performance coefficients obtained from the ICE bench test. The results are shown in Table 2 and Figure 2.

From the comparison in Figure 2, it can be seen that the performance coefficient of the ICE calculated by the SP differs very little from the data obtained from the ICE bench test, and the maximum error is about 2.7%, which meets the requirements for the experimental error. In other words, the MATLAB/Simulink SP has high calculation accuracy and meets the requirements of simulation calculation, which can be applied to calculate the performance coefficient of ICE.

Table 2. ICE performance coefficients

	1500	2000	2500	3000	3500	4000	4500	5000
Simulation results	94	107	126	135	148	157	132	138
Experimental results	91	108	124	136	152	156	130	136

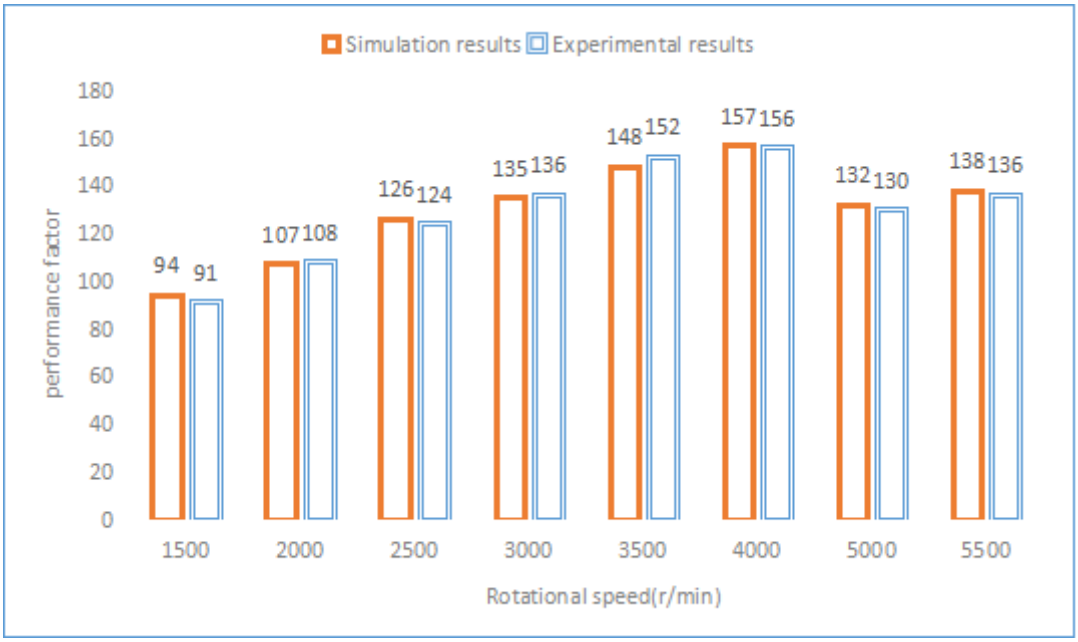


Figure 2. Comparison of performance coefficients

4.2. Optimization Analysis of MaC System

The development of the test bench MaC system with the help of MATLAB graphical programming software reduces the complexity of the program design and allows the developer to focus more on the engineering problems that need to be solved. The means of performance improvement vary, but they can all increase the execution speed and improve the operation efficiency of the system to a certain extent, so it is necessary to optimize the performance of the software of the MaC system that has been designed and has certain functions. Performance optimization is a continuous cycle of the process, as shown in Figure 3.

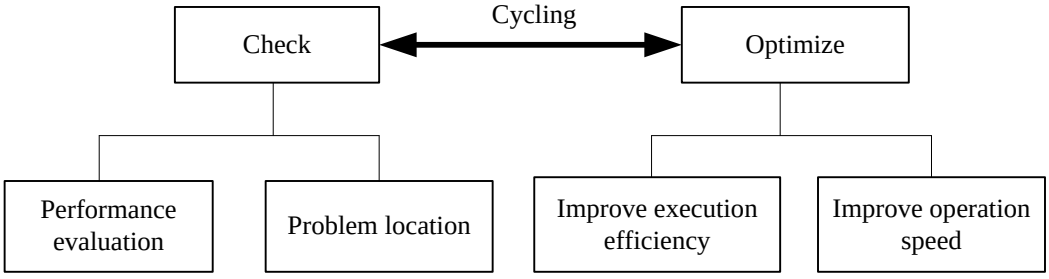


Figure 3. Performance cycle optimization process of MaC system

5. Conclusion

In this paper, a test bench MaC system for ICEs is developed based on MATLAB software. In order to meet the high performance requirements of the software operation of the MaC system, Simulink is used as the human-machine interface of the MaC system to provide intuitive monitoring and test analysis functions. This paper uses both MATLAB simulation and control technology to validate a new method of evaluating the performance of ICEs, and concludes that the application of MATLAB to calculate the performance coefficients of the MaC system is effective, and the MATLAB software can also optimize the performance of the MaC system.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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